TITLE

Within-session reliability for inter-limb asymmetries in ankle dorsiflexion range of motion during the weight-bearing lunge test

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ABSTRACT

Background: The identification of asymmetrical inter-limb ankle dorsiflexion range of motion (DF ROM) has the potential to influence the course of treatment during the rehabilitation process, with limitations in ankle DF ROM potentially increasing injury risk. However, reliability for identifying ankle DF ROM asymmetries has not yet been established.

Hypothesis/Purpose: i) To establish values of ankle DF ROM asymmetry; ii) to identify the influence of leg dominance on inter-limb asymmetries for ankle DF ROM; iii) to determine the reliability of the trigonometric measurement method during the weight-bearing lunge test (WBLT) for both a single limb and the asymmetry values.

Study Design: Cross-sectional study.

Methods: Ankle DF ROM was measured bilaterally in 50 healthy and recreationally active participants (28 men, 22 women, age = 22 ± 4 years, height = 172.8 ± 10.8 cm, body mass 71.5 ± 15.1 kg), using the trigonometric measurement method during the WBLT. Each ankle was measured twice in a single testing session to establish within-session reliability.

Results: Values are presented for asymmetries in DF ROM. No differences were identified between the dominant and non-dominant limb ($P = 0.862$). Within-session reliability for measuring a single limb was classified as 'good' (ICC = 0.98) with a minimal detectable change value of 1.7°. For measuring ankle DF ROM asymmetry, reliability was established as 'good' (ICC = 0.85) and a minimal detectable change value of 2.1°.

Conclusions: Although symmetry in ankle DF ROM may not be assumed, the magnitude of asymmetry may be less than previously reported in a population of recreationally active individuals. Discrepancies between previous research and the findings of the present study may have been caused by differences in measurement methods. Furthermore, clinicians

should be aware that the error associated with measures of asymmetry for ankle DF ROM during the WBLT is greater than that of a single limb.

Level of Evidence: 2b

Key words: ankle dorsiflexion, inter-limb asymmetry, reliability.

INTRODUCTION

During many athletic activities, ankle dorsiflexion range of motion (DF ROM) is required for the efficient dissipation of ground reaction forces.[1,2] Limited ankle DF ROM has been reported to affect lower-limb force profiles within athletic activities, as ankle DF ROM restriction has been shown to correlate with greater peak vertical ground reaction forces during landings.[2] As a result, athletes with limited ankle DF ROM may exhibit movement strategies with gross technical errors during bilateral[2-4] and unilateral[3,5] squatting and landing tasks, as well as during gait.[6] Reduced weight-bearing ankle DF ROM has been identified as being a modifiable risk factor for many lower limb injuries, with weight-bearing ankle DF ROM of 34° being associated with 2.5 times greater injury risk in military recruits.[7] Proximally, a limitation in weight-bearing ankle DF ROM has been shown to present as a risk factor for hamstring strains in Australian football athletes (relative risk = 2.32).[8] Furthermore, elite junior basketball players with weight-bearing ankle DF ROM values <36.5° possess a 18.5% to 29.4% risk of developing patella tendinopathy within a year.[9] This risk is significantly greater than the 1.8% to 2.1% for players with >36.5° ankle DF ROM.[9] Therefore, restrictions in weight-bearing ankle DF ROM may increase injury risk through the development of mechanical compensations during athletic activities.

Restrictions in ankle DF ROM may result from injury to the rearfoot complex and have been identified.[10] Furthermore, changes in ankle DF ROM have been suggested to occur in response to the functional demands placed on the ankle complex.[11] As such, athletes with a history of lower-leg injury or those exposed to asymmetrical loading might have an inter-limb asymmetry in ankle DF ROM. Although current literature does not provide a clear understanding of the influence inter-limb asymmetries may have on an athlete's performance,[12] asymmetries in ankle DF ROM have been positively correlated with performance deficits during change of direction tests.[13]

However, research investigating normative values for weight-bearing ankle DF ROM has provided conflicting evidence regarding the extent of asymmetries.[11, 13-16] Cosby and Hertel[14] showed only a 0.8˚ difference in weight-bearing ankle DF ROM using a lunge test with a bent knee. Similarly, Konor et al[16] found no difference between left and right sides during the weight-bearing lunge test (WBLT) in healthy adults. However, normative data from Hoch and McKeon[15] demonstrated inter-limb asymmetries for ankle DF ROM in healthy participants frequently reached 1.5 cm when measuring toe-wall distance. Furthermore, Rabin et al[11] identified greater ankle DF ROM for the non-dominant leg exceeding 10° in 23% of male military recruits.

Better delineation of relative ankle DF ROM symmetry as measured in a weight-bearing position has several potential clinical and research purposes. Clinically, this information could be used to inform the course of treatment during the rehabilitation process or while prescribing interventions to increase ankle DF ROM. Furthermore, it is common practice to perform bilateral comparisons when assessing deficits in DF ROM, which might lead to diagnostic errors if symmetry is assumed. Without prior assessment and knowledge of normative DF ROM asymmetries, the rehabilitation program for an athlete with a similar asymmetry could be misjudged through a lack of consideration for the functional demands placed on the ankle joint.

In order to identify asymmetries in ankle DF ROM that are relevant to functional activities, it has been suggested that using an active weight-bearing assessment provides the most valid representation of ankle DF capacity during dynamic tasks such as squatting and landing.[3,17] As such, the WBLT has been the subject of many recent investigations.[16,18,19] However, a number of different measurement methods can be used to quantify ankle DF ROM during the WBLT, including measuring tibia angle with either a standard goniometer or inclinometer,[16,18] Achilles tendon angle with an inclinometer,[18] or the distance of the greater toe from the wall using a tape measure.[18,20] In an attempt to establish the most reliable method to measure ankle DF ROM during the WBLT, Langarika-Rocafort et al[18] compared five commonly used techniques; heel-wall distance, toe-wall distance, tibia angle, Achilles tendon angle and a trigonometric angle derived from heel-wall distance and ground-knee distance. The trigonometric measurement method was found to have the highest between-session intra-rater reliability (ICC = 0.95, SEM = 1.18˚) compared to measurements of tibia angle (ICC = 0.87, SEM = 2.17˚) and Achilles angle (ICC = 0.87, SEM = 2.28˚).[18] As a result, the trigonometric measurement method may present as a more reliable tool for the clinician to establish ankle DF ROM during the WBLT.

While the between-session intra-rater reliability of the trigonometric method has been established, the within-session intra-rater reliability has yet to be determined. Furthermore, the extent of inter-limb asymmetries in a young, healthy, and active cohort has yet to be established. The aims of this study, therefore, were: i) to establish values of ankle DF ROM asymmetry, ii) identify the influence of leg dominance on ankle DF ROM and iii) to determine the within-session, intra-rater reliability of the trigonometric measurement method during the WBLT in healthy and recreationally active participants for both a single limb and the symmetry values measured.

METHODS

Study design

Participants reported to the laboratory for a single testing session. Testing was conducted by the lead investigator who had 10 years' experience measuring ankle DF ROM during the WBLT and an accredited member of the British Association of Sport Rehabilitators and Trainers. Prior to data collection, all participants completed a pre-exercise questionnaire and provided written informed consent. Following the recording of height and body mass, participants reported their dominant leg, defined as their preferred leg for kicking a ball. Ankle DF ROM for both legs was then measured using the WBLT with no prior warm-up using a randomized counterbalanced design. Following a 10-minute rest, participants were re-tested in order to determine within-session reliability of the WBLT using the trigonometric measurement method.

Participants

Using the findings of Rabin et al[11] for inter-limb asymmetries for ankle DF ROM between the dominant and non-dominant limb (effect size = 0.83), we performed a representative analysis to determine the appropriate sample size based on. Calculations indicated that to achieve 80% statistical power, a minimum of 39 participants were required to detect inter-limb asymmetries. A total of 50 participants volunteered for the study (28 men, 22 women, age = 22 ± 4 years, height = 172.8 ± 10.8 cm, body mass 71.5 ± 15.1 kg). All participants self-reported to be physically active, defined as regularly performing at least 30 min of moderate intensity physical activity 3 times per week for at least 6 months prior to testing.[5] Participants were excluded if they had a history of a lower-extremity surgical procedure or injury to the lower-extremity in the six-months prior to testing. Ethical approval was provided by the lead authors institution’s Research Ethics Panel.

Procedures

In order to measure the heel-wall distance, a 70 cm tape measure was fixed to the floor, perpendicular to the wall used for testing. Measurements of ground-knee distance were obtained with a 70 cm tape measure fixed vertically to the wall and perpendicular to the tape measure on the ground. A longitudinal line was marked down on each of the scales for testing purposes. Prior to performing the test, participants were provided with a demonstration and standardized instructions. Participants then completed three familiarization trials for each leg before performing three trials on each limb, with the mean value from the three attempts from each foot being used for data analysis.

To ensure neither the participant nor investigator could target a specific outcome on subsequent attempts, no markings were made on the tape measure that would indicate the previous attempt. Following a 10-minute break participants were retested using the same procedures on both legs in order to establish within-session reliability. The results were recorded on a separate sheet in order to blind the investigator from previous distances and participants were not informed of their previous scores. For all participants, leg order was randomized for both trial 1 and 2. Ankle DF symmetry was calculated in degrees as the absolute difference between the means of the right and left legs. See figure 1 for an illustration of testing procedures and measurements used for the trigonometric calculation.

INSERT FIGURE 1 HERE

Participants began the test by facing a bare wall, with the greater toe of the test leg positioned against the wall. The greater toe and the center of the heel were aligned using the marked line on the ground. Participants were instructed to place the non-test foot behind them, with the heel raised and at a distance that they felt helped maximize their performance on the test. This position was established during familiarization. In order to maintain balance, participants were asked to keep both hands firmly against the wall throughout. The participants were then instructed to slowly lunge forward by simultaneously flexing at the ankle, knee and hip on the test leg in an attempt to make contact between the centre of the patella and the vertical marked line on the wall. No attempt was made to control trunk alignment. Subtalar joint position was controlled by keeping the test foot in the standardized position and ensuring the patella contact with the vertical line was accurate.[16]

The aim of the test was for the participant to get their heel as far away as possible from the wall, while making contact between the patella and the wall and maintaining firm pressure between the heel and the ground. Throughout the test, the investigator was positioned behind the participant in a low crouched position in order to visually monitor heel-lift. Heel lift was defined as the visual lifting of the calcaneus, resulting in a greater ground surface area observed under the rearfoot. Any elevation of the heel during the test was regarded as a failed attempt and feedback was provided to the participants regarding their inability to prevent the heel from rising.

Upon successful completion of an attempt, where contact between the patella and the wall was made with no change in heel position relative to the ground, participants were instructed to move the test foot further away from the wall by approximately 0.5 cm. No restrictions were placed on the number of attempts made by a participant. At the last successful attempt, the distances between the heel and the wall, and the distance between the anterosuperior edge of the patella and the ground were recorded to the nearest 0.1 cm. Ankle DF angle for each attempt was calculated with the heel-wall and ground-knee distances, using the trigonometric function outlined by Langarika-Rocafort et al[18] (DF ROM = 90- arctan[ground-knee/heel-wall]).

Statistical Analysis

The assumption of normality for data sets was checked using the Shapiro-Wilk test, with normative data for the inter-limb mean difference for ankle DF ROM graphically presented using a frequency-distribution histogram. An independent *t*-test were performed to establish the difference between the dominant and non-dominant for ankle DF ROM during the WBLT. Effect sizes were calculated for each comparison, with 0.2 being considered *small*, 0.5 *moderate* and 0.8 or greater *large*.[21]

The within-session intra-rater reliability for single limb measurements of ankle DF ROM and ankle DF symmetry was initially assessed using a paired samples *t*-test to calculate systematic bias between trial 1 and 2.[22] Relative reliability was determined using intra-class correlation coefficient (ICC) calculated as suggested by Hopkins[23] and reported with 95% confidence intervals, with ICCs interpreted as follows: 0.00-0.25 *poor*, 0.26-0.50 *fair*, 0.51-0.75 *moderate*, and 0.76-1.00 *good* reliability.[24] Absolute reliability was calculated using the coefficient of variation (CV; SD / mean *100), the 95% limits of agreement, standard error of measurement (SEM; $SD\sqrt{1-ICC}$)[22] and minimal detectable change (MDC; $SEM*1.96*\sqrt{2}$).[25] All statistical tests were performed using SPSS® statistical software package (v.24; SPSS Inc., Chicago, IL, USA), with the *a-priori* level of significance set at $P < 0.05$. ICC and CV% were calculated using a customized spreadsheet.[26]

RESULTS

The mean difference for ankle DF ROM was 2.3˚ ± 2.0˚. Forty-one participants (82%) reported their dominant leg to be their right, with the remaining nine participants (18%) reporting their left leg as dominant. WBLT values are summarized in Table 1. Mean WBLT values for the dominant and non-dominant limb were 36.5 ± 4.5˚ and 36.5 ± 4.3 ˚, respectively. No statistical difference was identified between the dominant and non-dominant limb.

INSERT FIGURE 2 AND TABLE 1 HERE

The within-session reliability of the WBLT is summarized in Table 2. There were no systematic biases for the WBLT using the trigonometric measurement method between trials for either ankle DF ROM or ankle DF symmetry ($P > 0.05$). The relative reliability was established as 'good' for within-session reliability for a single measure (ICC = 0.98) and inter-limb asymmetries in ankle DF ROM (ICC = 0.85). All values representing relative and absolute reliability are reported in Table 2.

INSERT TABLE 2

DISCUSSION

The primary aim of this study was to establish values for the inter-limb asymmetries of ankle DF ROM during the WBLT among healthy recreationally active individuals. Of all participants, 44% presented asymmetries in ankle DF ROM exceeding the MDC of 2.1° found in this investigation (Table 2), with 8% of participants demonstrating an inter-limb asymmetry greater than 5°, with the largest asymmetry being 8.8°. Therefore, with 44% of our sample having asymmetry values greater than the MDC, our findings suggest that the clinician should not assume symmetry without conducting thorough *a-priori* assessments.

Our data support the findings of Hoch and McKeon[15] and Rabin et al[11], by identifying the existence of inter-limb asymmetries in ankle DF ROM during the WBLT in healthy populations. Using the toe-wall distance during the WBLT, Hoch and McKeon et al[15] reported that 68% of participants exhibited an asymmetry of 1.5 cm or less, with some participants approaching asymmetries of approximately 3 cm. Using the conversion calculation suggested by Konor et al[16] where 1 cm in toe-wall distance corresponds with approximately 3.6˚ of ankle DF ROM, 32% of the sample in Hoch and McKeon[15] demonstrated ankle DF ROM asymmetries of > 5.4°, with some participants approaching asymmetries of 10.8°. This is similar to that of Rabin et al[11], where 64 healthy male military recruits possessed a bilateral mean difference of 5.8° in favour of the non-dominant leg during the WBLT. Equally, 23% of participants had asymmetries >10°.[11]

Although our findings support the notion that bilateral differences are present in healthy populations, our data indicate that the magnitude of inter-limb asymmetry for ankle DF ROM is likely less than previously reported. Our findings identify a much smaller mean asymmetry in comparison to previous investigations,[11,15] with 56% of our population possessing inter-limb asymmetries on the WBLT of less than the MDC of 2.1°. This resulted in rightward skew of our data (Figure 2), indicating that a large portion of our sample presented with a negligible asymmetry in ankle DF ROM, relative to the MDC. Furthermore, none of the participants who volunteered for our study exceeded an asymmetry of 10°, with the greatest asymmetry recorded being 8.8° between limbs.

One possible reason for not observing a similar magnitude in asymmetry may be the measurement method of ankle DF angle. Both measurement methods adopted by Hoch and

McKeon[15] and Rabin et al[11] used to record ankle DF ROM during the WBLT have been identified to possess a greater MDC for a single limb than the 1.7˚ found in our investigation (Table 2).[18] As the MDC represents the boundaries of measurement error,[25] it is possible that the testing procedures used by both investigations may have contributed to the level of inter-limb asymmetry observed. For example, the MDC for the measurement method used by Rabin et al[11] has been reported to be 6.0˚ for testing a single limb.[18] Although it is unclear why the trigonometric measurement method provides greater reliability than other measurements of ankle DF ROM during the WBLT,[18] it may be that measuring distances produces superior repeatability than measurements of angles. This suggestion is supported by Langarika-Rocafort et al,[18] where ICC values for all distances associated with the trigonometric method were much higher (ranging 0.95 – 0.96) than measuring tibia (0.87) and Achilles angle (0.87) during the WBLT.

To our knowledge, no previous investigation has established the within-session intra-rater reliability for measuring asymmetries in ankle DF ROM during the WBLT. Our findings indicate that the error in measurement for inter-limb differences in ankle DF ROM (MDC = 2.1˚) is greater than the error associated with testing a single limb (MDC = 1.7˚). Measurements of tibia angle for single limb ankle DF ROM during the WBLT have previously been shown to possess MDC values >6.0˚.[18] As our investigation showed greater error associated with measures of inter-limb asymmetries in ankle DF ROM, the mean inter-limb difference of 5.8˚ in ankle DF ROM (measured as tibia angle) reported by Rabin et al[11] may represent error in the measurement technique that is compounded by testing both limbs. Although other investigations have reported intra-rater MDC values as low as 3.2˚ when measuring tibia angle for a single limb,[19] none have established the reliability for measuring asymmetry. Therefore, it remains possible that the difference between the findings of Rabin et al[11] and that of our study is due to measurement error associated with the techniques employed to establish inter-limb differences in ankle DF ROM.

No systematic bias was found in our data between trials using the within-session design. This demonstrates that the procedures were well-controlled during testing. As a result, learning effects, acute changes caused by the previous trials (e.g. fatigue or warming up of relevant tissues) and participant bias were not confounding factors during testing.[25] This is an important consideration for clinicians when administering the WBLT in practice in order to establish real measurements in ankle DF ROM, with poor control of conditions negatively impacting the clinician's ability to interpret data.

Within the present study, the MDC for a single limb measurement for ankle DF ROM during the WBLT was identified as 1.7°, with a SEM of 0.6° (Table 2). These values for reliability are lower than reported for alternative measurement methods of ankle DF ROM during the WBLT, with MDC and SEM values ranging between 3.1˚ to 6.4˚ and 1˚ to 2.4˚, respectively.[19] Although all reported methods for measuring ankle DF ROM during the WBLT have been identified as 'good' (ICC >0.7),[19] Langarika-Rocafort et al[18] demonstrated that the trigonometric measurement method used in our study possessed the highest intra-rater reliability and smaller MDC value in comparison to four other measurement methods. Based on our results and those reported by Langarika-Rocafort et al[18], we posit that the trigonometric method should be used when measuring ankle DF ROM asymmetries, as it appears to be a more sensitive measure. Practically, the trigonometric method does not require specialised equipment, is time efficient and presents as a simple method for calculating ankle DF ROM.[18] Regardless, clinicians and practitioners should be aware of the different results based on the method used, so as to avoid erroneous conclusions when comparing their patients' or clients' results to the literature.

Despite our study using the same measurement technique as Langarika-Rocafort et al[18], we report an improved reliability. We speculate that one potential reason may be due to the administration of the WBLT. In order to identify peak ankle DF angle during the WBLT, Langarika-Rocafort et al[18] relied upon participants informing the investigator of when they had reached maximum distance from the wall prior to measurement. In contrast, our measurement was taken at the last successful attempt, which was defined as the furthest distance away from the wall where they could make contact between the patella and the wall and prior to the point of heel lift. These two approaches are markedly different and are likely to produce different results. Heel lift was carefully monitored by the investigator and defined as the visual lifting of the heel, where a greater surface area of the ground could be seen under the rearfoot. We believe that this is an important distinction, as it is questionable that participants can identify at what point ankle DF ROM has terminated and compensatory strategies will be adopted, thus influencing the outcome measurement through a lack of standardization. This is especially problematic during the WBLT, as participants are unable to observe ankle motion on the test leg and the accuracy of identifying movement strategy, primarily through the sensorimotor system varies by task.[27]

Leg dominance has previously been shown to possess a relationship with inter-limb asymmetry in ankle DF ROM, with greater ankle DF ROM observed in the non-dominant limb.[11] However, our results did not identify a difference in ankle DF ROM during the WBLT between the dominant and non-dominant leg. Although it remains unclear why we did not see a similar finding within our investigation, a few possibilities exist. Firstly, Rabin et al[11] proposed that asymmetries in ankle DF ROM between the dominant and non-dominant leg may exist due to the mechanical loading placed on the ankle complex during habitual activities. This is based on a rationale that the ankle joint complex adapts to the demands imposed upon it, with the non-dominant leg being subjected to larger requirements for balance and stability, resulting in greater joint ROM.[11] As all participants in Rabin et al[11] were military recruits, it may be that specific physical activities undertaken by the participants in preparation for basic military training resulted in the ankle DF ROM asymmetries identified between the dominant and non-dominant leg, as opposed to our sample who were physically active but not military trained.

Another possible explanation for the lack of agreement may be due to difference in procedures when conducting the WBLT. Unlike our study that used the trigonometric measuring method for recording ankle dorsiflexion ROM, Rabin et al[11] used an inclinometer placed on the tibia, 15 cm below the tibial tuberosity. As previously discussed, intra-rater reliability for this method has been reported to be inferior to the trigonometric method.[18] As an analysis of intra-rater reliability was not conducted as part of Rabin et al[11] design, it is possible that the procedures used may have contributed to the contrast in findings.

Whether the asymmetry in ankle DF ROM observed in this investigation is clinically meaningful is at present unknown. Limitations in ankle DF ROM have been linked to greater peak forces[2] and increased knee abduction moments[28] during landing activities and these suboptimal movement strategies are associated with ACL injuries.[29] Large asymmetries in ankle DF ROM may, therefore, present as a modifiable variable for reducing risk factors associated with lower extremity injury during dynamic activities.

Asymmetry in ankle DF ROM has been shown to impact change of direction performance. Gonzalo-Skok et al[13] found a negative relationship between ankle DF ROM asymmetry during the WBLT and 180° change of direction test in elite youth male basketball players. As weight-bearing peak DF angle can approach approximately 50° during change of direction tasks,[30] it is likely that limitations in ankle DF ROM have the potential to alter movement patterns during such athletic activities. This may result in asymmetries in ankle DF ROM contributing to suboptimal movement strategies to be utilized on the limited side, leading to reduced performance in athletic tasks. Unfortunately, Gonzalo-Skok et al[13] did not report values for inter-limb asymmetries and, therefore, it is unclear if the asymmetries found in our study have the potential to negatively impact performance. More research is required to establish a threshold for when an asymmetry may present as a risk factor for the development of injury or a cause towards suboptimal performance.

Our results indicate that ankle DF symmetry should not be assumed by the clinician. The assumption of symmetry in ankle DF ROM during the rehabilitation of an athlete would be inappropriate for restoring function. Instead, it may be more reasonable to identify whether the athlete possesses sufficient ankle DF ROM to cope with the movement demands placed on them by the sport and relevant training. As athletic activities, such as squatting,[31] landing,[32] running[33] and change of direction tasks[30] may all require large quantities of ankle DF, ensuring an athlete possesses sufficient ROM to cope with these demands appears to be a more logical guide.

Our investigation was not without limitations. Firstly, we used a relatively young population of recreationally trained individuals. As such, the findings presented in our study provide preliminary data and are not yet representative of a wider population. Further work is required to establish normative values across the wider population. The degree to which asymmetry in ankle DF ROM becomes clinically relevant is currently unclear. Whether a threshold exists that may increase an athlete’s injury risk or result in a decline in performance outputs requires further investigation in order to inform a clinician’s practice.

During testing, as the investigator was not blinded to the measurements, it is possible that the investigator had knowledge of the initial values. Although an attempt was made to control for this, recollection of values may have occurred. This investigation also used only one, experienced tester to establish values during the WBLT. Therefore, these results are not generalizable to the novice clinician. Furthermore, the intra-rater reliability for the trigonometric measurement method has not yet been established. Without data on the inter-rater reliability the wide-spread adoption of this measurement technique should be used with caution.

CONCLUSIONS

Recreationally active individuals may present with asymmetrical weight-bearing ankle DF ROM during the WBLT that is normal and not necessarily associated with leg dominance. Our findings suggest the extent of asymmetry found using this technique is less than what has been previously reported in the literature. Furthermore, measuring weight-bearing ankle DF ROM for a single limb using the trigonometric method presents as a simple and reliable tool; however, the error associated with identifying asymmetries in weight-bearing ankle DF ROM may exceed the absolute inter-limb difference. Therefore, asymmetries in weight-bearing ankle DF ROM may be error associated with the testing procedures and not a true inter-limb difference. Future investigations should look to identify the intra-rater reliability of the trigonometric measurement method, as well as investigating the mechanical implications of ankle DF ROM asymmetry during functionally relevant activities.

REFERENCES

1. Yeow CH, Lee PVS, Goh JCH. Non-linear flexion relationships of the knee with the hip and ankle, and their relative postures during landing. *Knee*. 2011;18:323-328.
2. Fong CM, Blackburn JT, Nocross MF, et al. Ankle-dorsiflexion range of motion and landing biomechanics. *J Athl Train. 20*11;46:5 – 10.
3. Dill KE, Begalle RL, Frank BS, et al. Altered knee and ankle kinematics during squatting in those with limited weight-bearing-lunge ankle-dorsiflexion range of motion. *J Athl Train*. 2014;49:723–32.
4. Macrum E, Bell DR, Boling M, et al. Effect of limiting ankle-dorsiflexion range of motion on lower extremity kinematics and muscle-activation patterns during a squat. *J Sports Rehabil*. 2012;21:144–150.
5. Mauntel TC, Begalle RL, Cram TR, et al. The effects of lower extremity muscle activation and passive range of motion on single-leg squat performance. *J Strength Cond Res*. 2013;27:1813–1823.
6. Ota S, Ueda M, Aimoto K., et al. Acute influence of restricted ankle dorsiflexion angle on knee joint mechanics during gait. *Knee* 2014;21:669-675.
7. Pope R, Herbert R, Kirwan J. Effects of ankle dorsiflexion range and pre-exercise calf muscle stretching on injury risk in army recruits. *Aust J Physiother*. 1998;44:165–172.
8. Gabbe BJ, Bennell KL, Finch CF, et al. Predictors of hamstring injury at the elite level of Australian football. *Scand J of Med Sci Sports*. 2006;16:7–13.
9. Backman LJ, Danielson P. Low range of ankle dorsiflexion predisposes for patellar tendinopathy in junior elite basketball players: a 1-year prospective study. *Am J Sports Med*. 2011;39:2626–2633.

10. Reid A, Birmingham TB, Alcock G. Efficacy of mobilization with movement for patients with limited dorsiflexion after ankle sprain: a crossover trial. *Phys Canada.* 2007;59:166-172.

11. Rabin A, Kozol Z, Spitzer E, et al. Weight-bearing ankle dorsiflexion range of motion – can side-to-side symmetry be assumed?. *J Athl Train.* 2015;50:30-35.

12. Bishop C, Turner A, Read P. Effects of inter-limb asymmetries on physical and sports performance: a systematic review. *J Sports Sci.* 2018;36:1135-1144.

13. Gonzalo□Skok O, Serna J, et al. Relationships between functional movement tests and performance tests in young elite male basketball players. *Int J Sports Phys Ther*. 2015;10: 628-638.

14. Cosby NL, Hertel J. Relationships between measures of posterior talar glide and ankle dorsiflexion range of motion. *Athl Train Sports Health Care.* 2011;3;76-85.

15. Hoch MC, McKeon PO. Normative range of weight-bearing lunge test performance asymmetry in healthy adults. *Man Ther.* 2011;16;516-519.

16. Konor MM, Morton S, Eckerson JM. Reliability of three measures of ankle dorsiflexion range of motion. *Int J Sports Phys Ther*. 2012;7:279–287.

17. Whitting JW, Steele JR, McGhee DE, et al. Passive dorsiflexion stiffness is poorly correlated with passive dorsiflexion range of motion. *J Sci Med Sport.* 2013;16:157–161.

18. Langarika-Rocafort A, Emparanza JI, Aramendi JF, et al. Intra-rater reliability and agreement of various methods of measurement to assess dorsiflexion in the Weight Bearing Dorsiflexion Lunge Test (WBLT) among female athletes. *Phys Ther Sport.* 2017;23:37-44.

19. Powden CJ, Hoch JM, Hoch MC. Reliability and minimal detectable change of the weight-bearing lunge test: A systematic review. Man Ther 2015;20(4):524-532.

20. Bennell K, Talbot R, Wajswelner H, et al. Intra-rater and inter-rater reliability of a weight-bearing lunge measure of ankle dorsiflexion. *Aust J Physiother*. 1998;44:175–180.

21. Cohen J. *Statistical power analysis for the behavioural sciences*. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc; 1988.

22. Atkinson G, Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med*. 1998;26:217–238.

23. Hopkins WG. Precision of measurement. http://sportsci.org/resource/stats. Published November 2016. Accessed June 20, 2018.

24. Portney L, Watkins M. *Foundations of clinical research: applications to practice*. 3rd ed. Upper Saddle River, NJ: Prentice Hall Health; 2009.

25. Riemann BL, Lininger MR. Statistical primer for athletic trainers: the essentials of understanding measures of reliability and minimal important change. *J Athl Train.* 2018;53:98-103.

26. Hopkins W. Spreadsheets for analysis of validity and reliability. http://www.sportsci.org/resource/stats/index.html. Published June 2015. Accessed January 21, 2018.

27. Proske U, Gandevia SC. The proprioceptive senses: their roles in signaling body shape, body position and movement, and muscle force. *Physiol Rev.* 2012;92:1651-1697.

28. Malloy P, Morgan A, Meinerz C, et al. The association of dorsiflexion flexibility on knee kinematics and kinetics during a drop vertical jump in healthy female athletes. *Knee Surg Sports Traumatol Arthrosc.* 2015;23:3550-3555.

29. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes a prospective study. *Am J Sports Med.* 2005;33:492–501.

30. Riley PO, Kent RW, Dierks TA, et al. Foot kinematics and loading of professional athletes in American football-specific tasks. *Gait Posture.* 2013;38:563-569.

31. Kasuyama T, Sakamoto M, Nakazawa R. Ankle joint dorsiflexion measurement using the deep squatting posture. *J Phys Ther Sci.* 2009;21:195–199.

32. Zhang SN, Bates BT, Dufek JS. Contributions of lower extremity joints to energy dissipation during landings. *Med Sci Sports Exerc.* 2000;32:812-819.

33. Novacheck TK. The biomechanics of running. *Gait Posture.* 1998;7:77–95.

Table 1. Asymmetry within the weight bearing lunge test for dominant-to-non-dominant limb comparison (n=50).

Table 2. Within-session intra-rater reliability for the weight-bearing lunge test using the trigonometric measurement method for testing ankle DF ROM for a single limb and ankle DF symmetry (n=50).

Figure 1. Participant performing the WBLT with example calculation. Abbreviations: GK, ground-knee distance; HW, heel-wall distance; TA, trigonometric angle.

Figure 2. Frequency-distribution histogram for inter-limb mean difference with the weight-bearing lunge test (n=50).

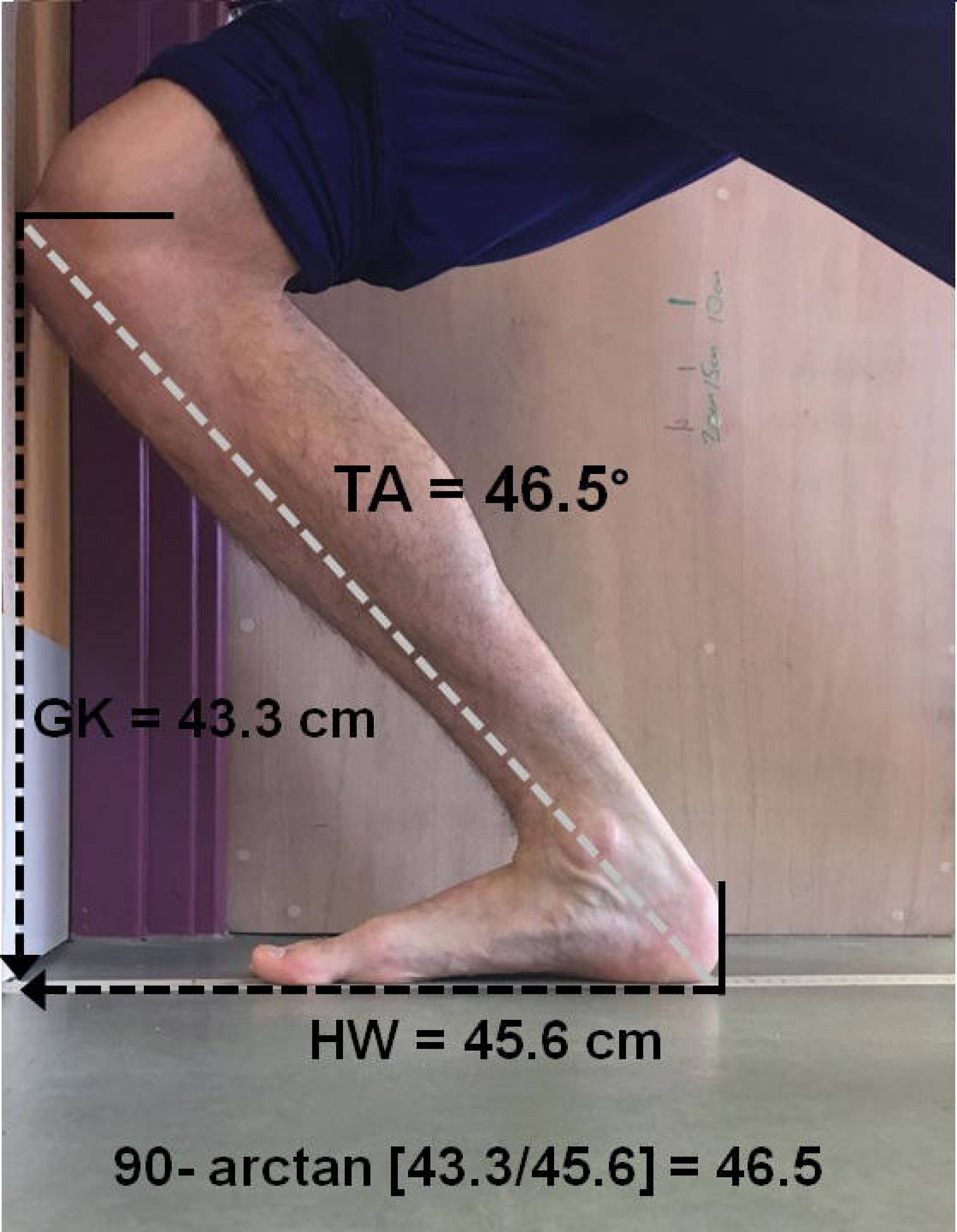
Table 1. Asymmetry within the weight bearing lunge test for dominant-to-non-dominant limb comparison (n=50).

Ankle dorsiflexion	Range of motion, ˚ (Mean ± SD)	Difference, ˚ (95% Confidence Interval)	Effect size
Dominant side	36.5 ± 4.5	-0.08 (-0.95, 0.80)	0.02
Nondominant side	36.5 ± 4.3		

[a] Significant difference (*P* < .05).

Table 2. Within-session intra-rater reliability for the weight-bearing lunge test using the trigonometric measurement method for testing ankle DF ROM for a single limb and ankle DF symmetry (n=50).

Reliability measure	Change in mean, ˚	ICC (95% confidence interval)	95% Limits of agreement, ˚	CV % (95% confidence interval)	Standard error of measurement, ˚	Minimal detectable change, ˚
Ankle DF ROM	-0.10	0.98 (0.97, 0.99)	0.1 ± 1.8	1.70 (1.50, 2.00)	0.6	1.7
Ankle DF symmetry	-0.03	0.85 (0.73, 0.92)	0.1 ± 2.2	91.4 (69.4, 135.0)	0.8	2.1


TA = 46.5°
GK = 43.3 cm
HW = 45.6 cm
90- arctan [43.3/45.6] = 46.5